

PAPER • OPEN ACCESS

Determination of Weight Coefficients for Stochastic and Fuzzy Risks for Multimodal Transportation

To cite this article: Vitalii Nitsenko *et al* 2020 *J. Phys.: Conf. Ser.* **1529** 032007

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

Determination of Weight Coefficients for Stochastic and Fuzzy Risks for Multimodal Transportation

Vitalii Nitsenko¹, Sergiy Kotenko², Iryna Hanzhurenko³, Keisha LaRaine Ingram⁴

¹ Private Joint-Stock Company "Higher education institution "Interregional Academy of Personnel Management", Frometivska str., 2, 03039 Kyiv, Ukraine

²⁻³ Institute of Market Problems and Economic-Ecological Research of the National Academy of Sciences of Ukraine, French Boulevard 29, 65044 Odessa, Ukraine

⁴ Mykolas Romeris University, Vilnius, Lithuania, Ateities st. 20, LT-08302

vitaliinitenko@gmail.com

Abstract. Research shows that the risks of multimodal transportation in the Northern ports of the Azov and Black seas, in real time, can vary by large quantities. This can cause significant problems for dynamic management of transportation, providing that transportation costs and time are minimized. Therefore, it is essential to formulate a mathematical model to determine the integral risk of freight traffic involved as it could help minimize the need for additional computer resources for the operation of logistics machinery. Determining the value of the integral risk is further complicated by the fact that the mathematical apparatus used for calculating stochastic and fuzzy risks tend to differ from one another. Therefore, an additional tool developed for the unification of various mathematical apparatus was done. The main task was conversion of local risks weight factors to components of integral risks, determined in actual time. The mathematical model has been tested for the dynamic management of freight traffic on the Black Sea ports - Mariupol, Odesa, Chornomorsk, Mikolaev, and Kherson. The route optimization was carried out for container and bulk cargoes, in particular, for grain cargoes. This allowed coverage for the whole range of risks that are inherent to multimodal transportation within the Azov-Black Sea region. The results confirmed that such an approach grants the possibility to choose routes with minimal transportation costs and time, as well as minimization of the use of computer resources.

Keywords: mathematical model, multimodal transport, multimodal transportation risks, fuzzy variables, stochastic parameters, dynamic system, simulation, seaports, risk assessment

1. Introduction

Transporting goods in the northern part of the Azov-Black Sea region is characterized by the risks involved, their impacts on costs and actual time which can vary significantly. This is confirmed by past unfortunate experiences of political and military threats on cargo delivery through the Kerch Strait to the Azov Sea ports. The work of logistics companies that perform multimodal transportation analysis is further complicated by this reason. Due to the problem of re-orienting goods already in transit to other routes, minimizing losses incurred as a result of dynamic change of individual chains from multimodal transportation. Minimized time for making risk reassessments and decisions to change the transportation route grants more time allocation to conduct the appropriate approvals,



organize overload and transportation on corrected routes. The classification of risks is given in Fig. 1 and, even their shallow analysis, considering the events in the Azov-Black Sea region and the rate of the identified risks, allows us to understand the complexity of the tasks faced by transport companies and logistics centers. Multimodal transportation is caused by the presence of a significant number of risks not only in the Azov-Black Sea region.

Many researchers [1, 2, 3, 4, 5] are engaged in the study of multimodal transportation, the formulation of its mathematical models for risk-modeling. Yet the main focus of researchers was primarily on risks of man-made accidents and those caused by other factors [3, 4, 5, 6].

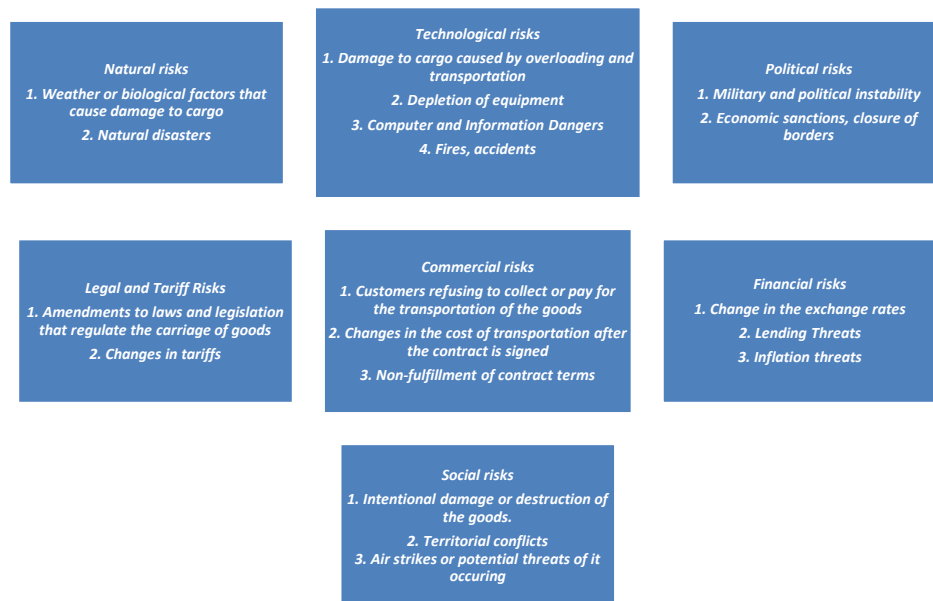


Figure 1. Classification of risks that may occur in the multimodal transportation of goods in the Azov-Black Sea region

Risk assessments and their impact on the integral risk of transportation were done for conditions where time change in the risk factor significantly exceeded the shipment time even for the longest route, in most studies the risk factors were assumed to be stable and identified [1-6]. Therefore, there was a problem of quickly determining the weighting factors and their set for changing the values of the parameters on which these risks were dependent on. Each risk of multimodal transportation, as a rule, is characterized by a large number of factors, which further complicates the assessment. In addition, there are both stochastic [7] and fuzzy risks in the set of multimodal transportation risks [8, 9].

For a mathematical description of these risks, different mathematical devices are used - the probability theory for stochastic risks cannot be used to identify fuzzy risks [8, 9].

Therefore, there are significant methodological difficulties in determining the risk of transportation on a particular route. The number of calculations greatly increases if the alternative routes of transportation become available on individual sections of the route. This requires, respectively, more time and computer resources for conducting calculations [9].

To reduce the calculation time, a database of probable transportation risks was created at each stage of cargo transportation for each of the possible routes.

2. The mathematical modeling of multimodal transport risks

As the analysis of existing risks of multimodal transportation from Fig. 1 illustrates, these risks do not have any signs of multiplicity, meaning that the strengthening / weakening of one of them does not amplify / weakened the other. That is, to calculate the risk for the whole route of transportation or so-called Integral risk of transportation, the principle of additivity of its components - local risks could be used. However, to create a universal model for finding integral risk, we have to consider the possibility of implementing both a multiplicative variant and additive variant of the formation of integral risk.

To achieve this, the coefficient of multiplicity c , was introduced, which was found by evaluating the degree of the multiplier effect. As shown by the experience of model approbation, the coefficient of multiplicity c , should not be applied to the whole array of risks, rather to their pairwise combinations. In the array of risks inherent in multimodal transportation, the probability of occurrence of three or more interrelated risks is too small and can be assumed to be zero.

When the multiplicity coefficient is set to > 1 , the risks increase the influence on each other, when values with < 1 - the risks weaken the influence on each other.

Then, to find integral risk, use the following functional dependence:

$$f_{sum} = c_{1-2} * (a_1 f_1 + a_2 f_2) + c_{3-4} * (a_3 f_3 + a_4 f_4) + c_{5-6} * (a_5 f_5 + a_6 f_6) + \dots \quad (1)$$

where f_1, f_2, f_3, \dots - the value of the relevant local risk, a_1, a_2, a_3, \dots - weight of i -th risk, where $i=1, 2, 3, \dots$, $c_{1-2}, c_{3-4}, c_{5-6}, \dots$ - coefficients of multiplicity of pairwise risks (respectively, 1-2, 3-4, 5-6 and so on).

Obviously, for a variant, when all the values of the multiplicity coefficient are equal to one ($c = 1$), formula (1) takes the form typical of the additive integral risk and then:

$$f_{sum} = \sum a_i * f_i \quad (2)$$

where f_i - the value of the i -th local risk, a_i - the weight of the i -th local risk.

The weight of a_i i -th risk can be interpreted as the degree of impact of the local risk value on the integral risk f_{sum} .

However, as shown by the case of the conflict in the Kerch Strait, the impact of one risk can be significantly higher than the impact of all risks. That is, one risk will have a so-called "absorbing" effect. The possibility of an absorbing effect of one of the local risks leads to the need to change the entire route or, when the cargo is already transported, to change the next sections of the route. In that case, the mathematical interpretation of integral risk can be represented as:

$$f_{sum} = \max\{f_1, f_2, f_3, \dots, f_i\} \quad (3)$$

To determine the local risks f_i the decomposition of the transportation problem into individual sections, or according to risk type, etc. is initially performed. That is, the boundaries of the second area of definition of local risk in the space with $(n+1)$ dimensions are identified, where n - the number of parameters that influence the i -th risk with the added dimension of the functional f_i .

After that, an interval of definition of i -th risk, its type (stochastic, fuzzy, etc.) are determined, the mathematical apparatus of its description is automatically selected. In conditions of using all the parameters of the impact on risk the volume of calculations is too cumbersome and the calculation time may be bigger than it is allowable for real tasks. Therefore, the problem of finding mathematical methods that contribute to the reduction of calculations arises. To do this, it is suggested to reduce the

problem by choosing, from the whole spectrum of the parameters of the influence on the risk, those whose influence is significant.

The boundary of the calculation's significance is determined by an expert. Then an approach analogous to the given by formula (1) can also be used to find the local risk value. It will take the following form:

$$f_i = \sum b_j * f_j \quad (4)$$

Where f_j – the value of the j -th component of the local risk, b_j – the weight of the j -th component of the specified risk.

When finding the f_i and f_j values following the described methods and using the formulas (1) and (2), the problem of finding an integral risk is encountered with the problem of determining the coefficients a_i and b_j .

As you know, stochastic risks can be described with the help of normal probability distribution, which is given through the probability density function. In its turn, the specified probability density function for multimodal transportation of goods is described by Gauss function.

When local risk depends on a very small number of stochastic factors, the assessment of the significance of their effects is simplified to known standard methods. Methodological difficulties appear for the cases of simultaneously fuzzy and stochastic quantities.

As already known, stochastic risks can be described using the normal probability distribution, which is given by the probability density function. The specified probability density function for multimodal transportation of goods is defined, in turn, by the Gauss function

$$f(y) = \exp[-(y - \varepsilon)^2 / 2\sigma^2] / \sigma\sqrt{2\pi} \quad (5)$$

where σ – mean square deviation, ε – mathematical expectation.

For $(n+1)$ dimensional definition area of the regression equation of the second order, it looks like this:

$$f(y) = A_0 + \sum_{i=1}^n A_i y_i + \sum_{i<l}^n A_{il} y_i y_l + \sum_{i=1}^n A_{ii} y_i^2 + \dots \quad (6)$$

where A_0 – free coefficient, that is, the coefficient of the regression equation that does not contain the unknown;

A_i – specific regression coefficients that determine the effect of the variable y_i on the value of the function $f(y)$;

A_{il} – coefficients that determine the effect of both the variable y_i and the effect of the variable y_l on the value of the function $f(y)$.

Then the coefficients a_i, b_j are uniquely determined by the matrix of the coefficients of the regression equation A (see formula 4).

Since the risks of multimodal transportation are often determined by the conditions of a fuzzy nature of the input data needed to define the risk and its components, the following approach is then used. Fuzzy parameters for finding a risk given the mathematical form of the problem are represented as a limited number of elements $\langle N, Y, \tilde{V} \rangle$, where N – is the value of the fuzzy input parameter, Y is specified as $(n+1)$ dimensional definition area of variables where, in turn, n – is the number of parameters that determine the risk.

Then the task is to find the fuzzy set of values $\tilde{V} = \{y, \mu_{\tilde{V}}(y)\}$ in the presence of a fuzzy input parameter N which is defined in the domain Y . In this set of values, the value $\mu_{\tilde{V}}(y)$ – is the function member of fuzzy variables y .

In case of large arrays of data on the factors influencing the risks, the use of mathematical apparatus of factor analysis leads to a significant amount of computer resources. Similar difficulties arise in the presence of fuzzy risk parameters. In order to reduce the amount of computer resources used to make real-time calculations using standard equipment, we suggest the use of the Boolean algebra apparatus instead.

In this case, the action order should be as follows:

1. The boundaries of the intervals for changing each of the parameters that affect a particular risk are determined.
2. The intervals found are divided into segments, the number of which is determined by an expert. Increasing the number of specified segments, on one hand, increases the accuracy of the calculation, on the other hand, leading to excessive use of computer resources.
3. Using minimized Boolean functions, a Boolean model of the specified risk in tabular form can be created.
4. An interpretation of the Boolean model of risk suitable for future use can be done.
5. All results derived form a database which reduce the use of computer resources and the time needed to carry out operative analysis and route adjustment of multimodal transportation of cargo. For the sake of representing the Boolean function in analytical form, it was necessary to have a so-called, perfect disjunctive normal form (d.n.f.), with respect to a definite final set of parameters on which one or other risks is dependent on.

The specified set of parameters or "finite normal form" is derived in a manner so that each disjunction will include each parameter of the set, in a given sequence. The construction of the algorithm involves the formation of a multidimensional table. Each table for an individual risk is formed with $z+1$ column where the variables $y_1, y_2, y_3, \dots, y_z$ are written alongside, with the addition of a separate column for the target function, and m lines filled according to the order of the stages of multimodal transportation of goods.

The range of each parameter and target function change is divided by a divider so that each part of the range has approximately equal numbers of values from the set of m parameters. Next, each value of the target function parameter and, accordingly, each line are given a binary code - unit to the partition, and zero - after it. That is, the table is given a boolean form. In the case where a complete set of parameters are unknown, a so-called "Minimal disjunctive normal form" is formed. The problem reduces the search for a disjunctive normal form for a minimum number of parameters K , i.e.:

$$K = \min_{\substack{\text{for all d.n.f. for} \\ \text{variables } y_1, y_2, y_3, \dots, y_n}} \sum_{i=1}^s r_i \quad (7)$$

where r_i – rank of conjunction, for which, respectively:

$$s \in Z \quad (8)$$

The perfect disjunctive normal form represents a set of conjunctions that are joined by disjunctive signs, that is, in mathematical form:

$$y_1 \wedge y_2 \wedge y_3 \wedge \dots y_n \quad (9)$$

Then, with each conjunction, the duplicate or denied parameters are deleted. Next, the disjunction removes the conjunctions, when there are options to their objections. The resulting disjunction should be checked for the presence of perfect form. An algebraic normal form with a perfect disjunctive

normal form can be represented as a polynomial with coefficients of zero and one, and, thus, one could obtain a set of parameters on which the risk is dependent on.

The consistent iterative use of the specified algorithm to find the set of parameters during the iteration procedure will allow the weight to be set for each parameter with better precision.

Increased accuracy in setting the value for the weight factor increases as the amount required to calculate the geometric progression. As experience shows, sufficient accuracy is 0.01.

The suggested algorithms allow determining weight coefficients for local risks, which are defined as fuzzy and stochastic parameters. Obviously, when some of the risks appear to be dependent both on stochastic and fuzzy variables, it is recommended to represent it as an additive function of two local risks, one that depends on the fuzzy, the other - on stochastic parameters. The weight of each of these risks is defined according to the probability of its implementation in the multimodal transportation of goods.

Similarly, the weight of fuzzy and stochastic risks in integral risk can be determined using the probability of each of these risks.

A detailed analysis of the risks, depending on the fuzzy and stochastic parameters concludes that they can be treated as risks that occur at different stages of transportation.

Similarly, the weight of fuzzy and stochastic risks in integral and can be determined using the probability of each through realization.

3. Conclusions and Future Work

The mathematical model of determining the integral risk of cargo transportation in conditions of stochastic and fuzzy parameters that influence its components - local risks was developed. To minimize calculations and computer resources, the challenges of operational findings due to integral risk reduces the problem of determining the components' weight coefficients which are termed- local risks.

It is suggested to create auxiliary databases on possible risks at each stage of transportation and a full set of probable parameters that determine the mentioned risks. Then, a dynamic change in transportation stages during the event of increased threats and, accordingly, risks, even with a large number of risk parameters, will not increase the time of calculations to unacceptable values. It allows minimizing possible economic losses, choosing a route with a minimum period of transportation, organizing logistic services for the cargo transportation route, providing transportation and overloading facilities at the new suggested stages of transportation.

The described model is tested for dynamic management of cargo transportation in logistics chains via the Black Sea ports of the Azov-Black Sea region - Mariupol, Odesa, Chornomorsk, Nikolaev, Kherson.

The calculations were carried out both for container transportation and for transportation of bulk cargoes, in particular, for grains. This allowed coverage for the whole range of risks inherent to multimodal transportation in the Azov-Black Sea region. The results showed that this approach allows selection of a route that corresponds to the operator-selected optimization criterion - minimum transportation costs or time.

References

- [1] Ngamvichaikit A.: The Competency Development of Multimodal Transportation Management for Logistics Professional in Thailand International Journal of Trade, Economics and Finance, 8, 1, 62-66, (2017).
- [2] Xiong G., Wang Y.: Best routes selection in multimodal networks using multi-objective genetic algorithm, Journal of Combinatorial Optimization, 28, 655-673, (2014).
- [3] Tsung-Yu Chou: A study on international trade risks of ocean freight forwarders Journal of Marine Science and Technology, 24, 4, 771-779, (2016). DOI: 10.6119/JMST-016-0311-1.

- [4] McNeil A.J., Rüdiger F., Embrechts P.: Quantitative risk management: Concepts, techniques and tools. Princeton University Press, Princeton (2015).
- [5] Ciesla M., Mrowczynska, Opasiak T.: Multimodal transport risk assessment with risk mapping Zeszyty naukowe politechniki slaskiej Seria: Organizacja i zarzadzanie, 105, 31-39, (2017).
- [6] Kononenko V.: Project scope optimization model and method on criteria profit, time, cost, quality, risk, 26th IPMA World Congress Proceedings. Conference Centre Creta Maris, Hersonissos, Crete, Grece, 287-293, (2012).
- [7] Fernández E., Yolanda Hinojosa Y., Puerto J., Saldanha-da-Gama F.: New algorithmic framework for conditional value at risk: Application to stochastic fixed-charge transportation European Journal of Operational Research, 16, 215-226, (2019).
- [8] Rainer M.: Risk Assessment in Container Security Using Fuzzy Logic. International Conference on Computing Logistics (2010).
- [9] Yi-Zhou Li, Hao Hu, Dao-Zheng Huang: Dynamic Fuzzy Logic Model for Risk Assessment of Marine Crude Oil Transportation Transportation Research Record Journal of the Transportation Research Board 2273(2273):121-127, (2012). DOI: 10.3141/2273-15.